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Systematization of Technological and Economic Risks for the Selection of new Technologies

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Abstract

In the face of the increasing internationalization of markets, rising cost pressure, and shorter product life cycles, manufacturing companies are facing increasing competition and innovation pressure. To secure competitiveness, the early development of new and innovative technologies and their implementation on the market as products or services is paramount. However, besides high potential benefits, new technologies are also associated with high risks regarding their technological feasibility as well as their estimated economic implications. Existing approaches of technology assessment usually focus on evaluating the technological potential, while the risks associated with these technologies are hardly considered. However, existing risks influence the probability of realizing the predicted technology potentials, making an exclusive assessment of the technological potentials by no means sufficient for an adequate evaluation of new technologies. Hence, the consideration of potential risks is of particular importance for the initial assessment and selection of technologies at an early stage. To promote the consideration of risks in technology assessment from a holistic perspective, this paper identifies both technological and economic risk factors of new technologies based on a systematic literature review. These risk factors are clustered and integrated into a framework which can be used to increase the reliability and validity of the assessment of new technologies.

Keywords

Risk Identification; Technology Assessment; Risk Factors; Risk Assessment; Technology Risk Assessment

1. Introduction

Driven by the increasing internationalization of markets, manufacturing companies are confronted with an increasingly competitive environment and rising cost pressure [1, 2]. This development is accompanied by the rapid growth of available knowledge and constantly changing customer needs, which leads to increasing dynamics of technological change [3] and shortening of product life cycles [3, 4]. Due to the resulting increase in development and competitive dynamics, companies are required to be more effective and to shorten development times [2]. In this uncertain and volatile situation, great relevance is attributed to the development and market launch of technological innovations [5–7] to achieve differentiation features [8] or cost advantages [9]. It is important to identify and prioritize the most promising technologies as early as possible to ensure efficient use of the limited monetary and personnel resources available to the company [2, 10].

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The development and market introduction of new, innovative technologies is associated with high uncertainties and risks besides the mentioned potentials [11]. These risks are illustrated by the high failure rate of innovative development projects of up to 80% [12, 13]. Thus, it is necessary to consider not only the potentials but also the risks of new technologies for an adequate evaluation and prioritization of technologies, since high risks can significantly reduce the probability of realizing the predicted technology potentials.

The risks associated with new technologies result from long development cycles and unpredictable changes in the market situation [14], thus, the forecast of market potentials of the respective technology is difficult and related to high uncertainty [15]. For instance, the implementation of the technology may fail due to a lack of development competence on behalf of the company, or the expected sales potential may not be realized after the market launch due to low customer acceptance [16]. In practice, the initial prioritization and selection of new technologies follow the subjective, experience-based assessment of the respective decision-makers [17]. These expert assessments have their limits, especially in the early assessment of innovative technologies, since there are usually no empirical values for an objective assessment of new technology or comparison with existing ones. [18]. Especially the technological potential is often predicted incorrectly in case of a high degree of technological novelty, as there is a lack of knowledge and experiences inside the company [11, 19].

Existing approaches for technology assessment focus primarily on the potential, applicability, and economic viability of technologies. Risk assessments are of secondary interest, despite the diverse risks associated with new technologies [20]. This paper aims to address the outlined demand for systemization and support in the risk assessment for technology selection. Following the general approach for risk assessment defined in the international norm for risk management ISO 31000, the fundamental basis for an adequate risk assessment is the identification and structuring of possible risks and their sources [21]. Hence, in the following, a systematization of technological and economic risk factors that occur during the development, application, and market launch of technologies is presented. The identified risk factors and derived systematic structure serve to support the evaluation and selection process of new technologies in manufacturing companies and thereby enable the identification and selection of the most promising technologies.

2. Methodology

The structure of the present work is based on the research process of applied science according to ULRICH (see Figure 1). This research process is used by the authors since it focuses on problems with practical relevance and is of particular importance in the context of engineering sciences. The approach applies models, which describe, explain, and configure certain parts of reality [22].

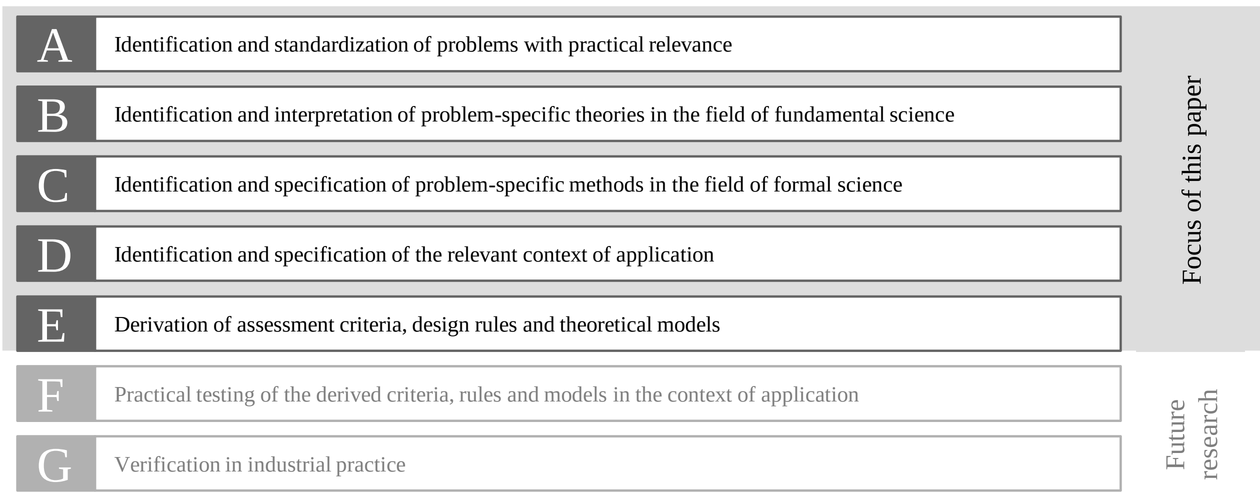

Figure 1. The research process of applied sciences according to ULRICH [22]

ULRICH's methodology consists of seven sequential process steps (A to G). Within this paper, steps A to step E are addressed. Section 1 first identifies and summarizes the problems with practical relevance to the subject area according to step A. In Section 3, the theoretical foundations of the problem are presented and defined in a problem-specific manner addressing step B. The methods and practical approaches in scientific literature relevant to the problem (step C) are then presented and explained in Section 4. Based on the problem definition and the theoretical foundations considered, the conceptual design of the model is presented in section 5 according to steps D and E. The results are then presented in section 5. Finally, a summary is given in section 6, and an outlook on further research demand according to steps F and G are pointed out.

3. Definitions and Fundamentals

In the following, the term risk as the fundamental object of consideration of this paper is defined. Furthermore, different dimensions of risk are outlined to enable a precise delineation of the paper's focus on technological and economic risks.

Risk is a component of various scientific disciplines, such as natural sciences, economics, and law [23]. As a result, there are various definitions of the term [24]. This paper is based on KNIGHT'S understanding of risk, who describes risk as measurable uncertainty and distinguishes it from true uncertainty. According to KNIGHT, both positive and negative deviations from a target variable are referred to as risk [25]. However, the risk assessment of new technologies aims at risks in the sense of threats, thus negative deviations. Following this general interpretation, only negative deviations are considered in this paper. Based on these explanations, the risk is defined in the course of this paper as follows: *Risk is a possible negative deviation from the desired target state in a decision-making situation under uncertainty, which is intrinsic to certain ventures and may pose a threat to the observer*.

In literature, there are various approaches to systematizing risks, which differentiate risk according to the management level (strategic, tactical, operational), the business unit affected (R&D, production, procurement, personnel, etc.), the factors to be used (operating resources, materials, personnel, capital, etc.), their cause (endogenous, exogenous) and their measurability, influenceability and severity [26, 27]. Furthermore, a differentiation is possible based on the innovation process phase of the technology, whereby risks are divided concerning the time of their occurrence [19, 28]. This paper aims to identify and structure different manifestations of technology's inherent risks. Thus, in the following different manifestations of risk will be derived from the scientific literature.

4. Related Work

In existing approaches in scientific literature, various procedures and methods for the evaluation of technologies are presented. In particular, these approaches focus on the evaluation of technological potential, economic efficiency, or the applicability of the technologies for the company, while risks are hardly considered [20]. Thus, these approaches are not relevant for the purpose of this paper. However, there are some approaches taking the risks of technologies into account, at least to some extent. In the review of existing approaches for the evaluation of technologies, the consideration of associated risks is therefore a prerequisite. To present the current state of research within the risk assessment of new technologies, these approaches are discussed in the following. For this purpose, the approaches are evaluated concerning the degree of risk assessment or the depth of risk systematization and the suitability for an assessment in the early phases of the innovation process of technologies.

JAHN [32] presents a methodology to evaluate innovative product technology projects, which can be used to prioritize and budget product innovations in the early phases of the innovation process. In addition to a potential analysis of the respective projects, the risks of the projects are considered depending on their maturity level. However, the method is focused on product technologies and therefore limited in the scope of application and comparability in the case of different technologies. Furthermore, only a limited set of criteria is used to assess the technology risk and, thus, the approach remains superficial.

A similar approach is presented by GRANIG [33]. The elaborated method is designed for the evaluation of innovation projects depending on the respective project phase and considers both qualitative and quantitative data for the evaluation. Theoretical financial approaches such as the discounted cash flow are used for the assessment. As already mentioned, the required monetary values are unknown and hardly predictable in the early phase. Thus, the applicability of the method is limited to later phases of the innovation process. Furthermore, potential risks are considered for the adjustment of the expected cash flow or the monetary value of the technology. However, the required basis for the assessment in form of a comprehensive structure of the risk is not provided.

HOROZ [34] introduces a procedure for assessing patent-relevant innovation projects based on the potential, risk, and monetary value of a technology. However, a distinct evaluation of the risks is not pursued in this approach, as risk is defined as the reciprocal of potential.

In the approach presented by WISSLER [35] a procedure for evaluating technical risks of serial products during the phases of product development is presented. Although this approach is partly suitable for the early phases due to the indicator-based assessment of technological features, neither economic risks are considered nor a quantification of the assessment results is performed, making the results hardly comparable.

In conclusion, the presented approaches offer limited applicability in early phases and lack comparability concerning the assessment results. Furthermore, the approaches particularly lack a thorough description of the possible risk and a detailed breakdown into individual risk factors. As a result, the risks associated with technology are not focused on and thus, insufficiently considered for the assessment of technologies. The identified weaknesses are subsequently addressed and a systematized structure of technological and economic risk factors affecting the potential of new technologies is presented.

5. Results

The elaboration of a systematic and comprehensive structure of technological and economic risk factors is performed within two main steps. Initially, risk factors need to be identified. Due to the extensive existing literature addressing the success or failure of technology development and innovation projects, it is not reasonable to carry out a baseline study for technological risk factors from the authors' point of view. Hence, a systematic analysis of the existing scientific literature is applied in section 5.1. Subsequently, the identified risk factors are to be operationalized by allocating them to the dimensions of technological and economic risk. The structuring is required to support the respective decision-makers in companies in the risk assessment and, thus, an efficient selection of new technologies. The structuring is done in section 5.2.

5.1 Identification of Potential Risk Factors

As a basis for the systematization of the risk factors, a systematic literature review according to BROCKE ET AL. (see Figure 2) was conducted. This procedure is used by the authors to ensure a profound basis for the explanatory model and to guarantee the comprehensibility and credibility of the research process. [36].

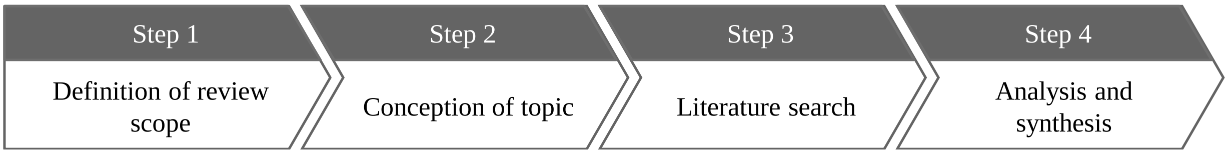

Figure 2. The literature review process according to BROCKE ET AL. [36]

The process consists of four steps. In *step 1*, the scope of the review is specified using an established taxonomy according to COOPER [37]. With the taxonomy, the context of the literature review is transparently described based on six characteristics. The taxonomy according to COOPER is shown in Figure 3.

Characteristic	Categories			
Focus	Outcomes	Methods	Theories	Practices or applications
Goal	Integration	Criticism	Identification of central issues	
Perspective	Neutral representation	Espousal of position		
Coverage	Exhaustive	Exhaustive and selective	Representative	Central or pivotal
Organization	Historical	Conceptual	Methodical	
Audience	Specialized scholars	General scholars	Practitioners or policy makers	General public

Legend: Selected category Unselected category

Figure 3. Taxonomy of literature reviews according to COOPER [37]

The *focus* of the conducted research is on results as well as applications of conducted studies regarding the risk analysis of new technologies. The *goal* of the research is in particular the integration of previous research findings to develop a new systematization that is as representative as possible. In terms of the *perspective*, the identification of risk factors is a neutral representation, as the risk factors are synthesized from existing works in the literature. Furthermore, the degree of *coverage* of the literature review is considered to be representative. Complete coverage can hardly be achieved due to the enormous amount of scientific publications in this area. Rather, a representative set of articles will be used for this work to focus on the most important risk factors in the model. Additionally, the *organization* of the results is a conceptual presentation, as the identified factors are transformed into a systematic framework. Lastly, the targeted *audience* of this paper is specialized professionals, to includes the results within methods and procedures of technology evaluation and selection.

In *step 2*, the conceptual preparation of the research topic is carried out to prepare the current state of the art of the research topic and to identify key terms on which the literature search is be based. For the conceptualization of the research topic and the identification of the key terms, BROCKE ET AL. recommend consulting standard literature and encyclopedias in which the topics are roughly presented [36]. In this paper, scientific literature focusing on risk management as well as technology assessment is examined first. For the topic of technology risk assessment, the following key terms, as well as their synonyms, are identified: *risk assessment*, *risk factor*, *uncertainty*, *technology risk*, *innovation*, and *new technology*.

Based on the defined scope, the literature search is carried out in *step 3*. Using the identified key terms, a keyword search was first performed in the literature databases Scopus, IEEE Xplore, SpringerLink, and Wiley Online Library to consider both English- and German-language literature. To narrow down the search results, relevant terms were linked with the Boolean operator "AND" and their synonyms were added with the "OR" operator. Following the database search, the identified publications were examined for their relevance concerning the objective of the literature search. For this purpose, the publications were first preselected based on their titles and then based on their addressed focus described in the abstracts. For the identified relevant publications, a forward and backward search was further performed according to the methodology of BROCKE ET AL. to identify additional relevant works or primary sources. In total, 33 publications were considered of particular relevance through this procedure [10, 11, 16, 19, 28–31, 34, 38–61].

The results of the identified publications are finally analyzed in *step 4* to synthesize the results into a useful framework. First, the findings of all publications were documented considering the scope of the research as well as the objective of the work, which corresponds to 247 risk factors. To delineate them from each other, synonyms were grouped, resulting in 28 different risk factors with different amounts of citations. The risk factors were prioritized and reduced according to the Pareto principle. This was done firstly, to reduce the complexity of the framework to increasing the applicability. Secondly, the exclusion of irrelevant risk factors prevents a falsification of the evaluation results and thereby increases the empirical accuracy of the model. According to the Pareto principle, the risk factors up to a cumulative number of references of 80% are selected for further processing, which ultimately corresponds to 19 risk factors. These factors are used to evaluate the risks associated with the development and implementation of new technologies and therefore represent the first step in risk assessment according to the international norm ISO 31000 for risk management [21].

Especially in the phase of synthesis and analysis, aggregations and summaries of the identified risk factors are made to ensure practicability and manageability. This is seen as acceptable from the authors' point of view considering the systematics as well as the proven validity of the used approach. The identified risk factors are structured and described in the following.

5.2 Structuring of the Risk Factors

As indicated above, 19 risk factors were identified based on the systematic literature review and the subsequent synthesis of the results. To guarantee practical use within technology assessment and selection procedures, the identified risk factors are structured in a three-level hierarchy consisting of risk type, sub-risks, and risk factors.

Technological risk		Economic risk			
Development risk	Implementation risk	Customer risk	Competition risk	Market risk	Monetary risk
Technological novelty	Process experience	Customer acceptance	Competitive differentiation	Market volatility	Fundraising
Technological complexity	Process complexity	Value communication	Competitiveness	Market position	Cost
R&D-resources	Quality		Technology substitution	Market barriers	
Technology interdependency			Technology imitation	Market novelty	

Legend: Risk type | Sub-risk | Risk factor

Figure 4. Systematization of identified risk factors of new technologies

The hierarchy aims to assist the respective decision-makers in the use of the risk factors in a systematic manner. For the systematization of the 19 identified factors, a cluster analysis [62] was used to arrange the factors based on their similarity, to achieve the highest possible homogeneity of the factors grouped within one cluster. The naming of the clusters derived in this way is based on the life cycle phases of technology, which pass through the development, implementation, and market phase [19]. To address the several perspectives of the market phase, this is further differentiated into the customer, competition, and market risks. To also take the frequently mentioned monetary risk factors into account, the sub-risk *monetary risk* was integrated into the systematization as a sixth cluster (see Figure 4) In conclusion, sub-risks are clustered in *development risk*, *implementation risk*, *customer risk*, *competition risk*, *market risk, and monetary risk...* Each sub-risk cluster is further described in the following.

5.2.1 Development Risk

The development risk combines the risk factors of *technological novelty*, *technological complexity*, *R&D resources*, and *technology interdependencies*. The risk factor of *technological novelty* indicates the risk that the potential of a technology is estimated incorrectly due to the degree of novelty and, thus, the technology does not fulfil the predicted functionalities [16, 63]. In contrast, *technological complexity* indicates the risk of a delayed or failed development due to excessive technological complexity and the resulting difficulty in controlling the development process [31]. Also, development can be delayed or aborted due to a lack of *R&D resources*, if the human or technical development resources available to a company and the available know-how are insufficient to develop or implement a new technology [11]. Furthermore, a delay in the development process can be caused by the non-availability of complementary technologies or production partners, which is taken into account by the risk factor *technology interdependencies* [11]. This aspect is particularly important in today's era of networked technologies and technology platforms, in which the number of technological subsystems and dependencies on complementary technologies is increasing rapidly [6].

5.2.2 Implementation Risk

In this paper, the implementation of technology is defined as the utilization or application of technology in the company, for example in the form of products or processes. This sub-risk comprises the risk factors *process experience*, *process complexity,* and *quality*. *Process experience* plays a decisive role in the transition of the technology into a serial product or the integration into the production process. Particularly in the case of new technologies, there is a lack of technological know-how, which makes it difficult to integrate the technology into the company's production system and therefore technology may not be used as anticipated [19]. Furthermore, the *process complexity* of technologies can also prevent successful integration [11]. Process complexity refers to the complexity of production technology or, in the case of product technologies, the complexity of the underlying production process of a technology, which can lead to integration difficulties or production breakdowns. Especially with new technologies, *quality risks* often occur, thus, the product or the production system does not meet the quality requirements [64]. The product quality influences the customers' willingness to pay and thus the economic success of the company [65, 66]. The non-fulfilment of the quality requirements is therefore described as a major risk of new products or the underlying technologies, especially in the context of increasingly complex products and rapidly changing customer requirements [64].

5.2.3 Customer Risk

Customer risks cover the risk factors of *customer acceptance* and *value communication*. In particular, *customer acceptance* is crucial for the success of new technologies. For novel technologies, the identification of customer preferences is usually problematic [30, 67]. Thus, there is a high risk that the technology fails to meet customer needs or does not match customer values and perceptions [68]. Secondly, customers lack understanding due to a low or no experience with a new technology, which increases the perceived risk associated with the purchase decision, finally reducing the acceptance of new technologies [69]. Furthermore, there is also a *risk in the communication* of the technology value to the customer. This factor describes the risk that the added value of technology cannot be communicated to the customer due to poor accessibility of the customer, poor marketing, or a poor image of the company [55]. However, communication of the added value of new technology is a prerequisite for the customer to understand the benefits of the technology and, therefore, a prerequisite for the diffusion of customer-oriented technologies in the market. [70, 71].

5.2.4 Competition Risk

In addition to the customer, the competition also has a decisive influence on the success of new technologies. The sub-risk relates to the risk factors of *competitive differentiation*, *competitiveness* (in terms of cost for example), and *technology substitution* as well as *imitation*. A fundamental element of innovation is doing things differently from competitors [50]. Thus, *competitiveness* and *differentiation* through new technologies are success factors in ensuring sustainable corporate profits. However, due to the usually poor predictability of actions of competitors, differentiation from the competition is perceived as a major challenge. In case it is uncertain whether the new technology has features differentiating them from existing and new competitive technologies, the respective technology has a high risk of competitive differentiation [16]. According to PORTER, relevant features for differentiation are costs, quality, or the benefits offered to a customer [72].

The risk of *substitution* is determined by uncertainty regarding the relative advantage of technology compared to other competitive technologies [29, 63]. For products, the threat of substitution increases with decreasing technological advantages compared to others, if competing products are available in the market. In this context, technology substitution is defined as the replacement of one technology by another that can replace the functionality of the existing one at least equivalently [73]. In the case of successful substitution, the success potential of the replaced technology is lost or at least limited. In addition to substitution, *technology imitation* is also a risk, especially in the case of poor protection options e.g. through patents [34]. Imitation is the adoption of processes or technologies by competitors and the subsequent offering of similar products or services in the market [74]. The risk of imitation depends on the ability and possibility of protecting technological competencies and is of equal importance as the preservation of being substituted concerning competitive advantages [75, 76].

5.2.5 Market Risk

The market risk consists of the risk factors *market volatility, market position, market barriers,* and *market novelty*. The risk factor *market volatility* comprises market dynamics, changes in the competitive structure, and fluctuating customer demands, which lead to rapid changes in market conditions [77]. Especially in growing, highly competitive markets, these aspects are described as major threats for companies [30, 78]. Crucial for the success of a technology is also the *market position* of the company or the technology [5, 55]. This refers to the strength or market share of the company in the corresponding market at the time of market introduction. The introduction of new technologies as products or processes in markets with a strong market position is less risky [55, 77, 79]. A strong market position supports the implementation of an industry-standard (dominant design) and may help in developing market barriers. *Market barriers* are "hurdles" that new competitors have to overcome when entering a new market, hence, they are referred to as a further risk factor concerning the introduction of new technologies or the development of new markets. MÜLLER-STEWENS ET AL. distinguish six types of market barriers: Economies of scale, customer loyalty, capital requirements, cost disadvantages, distribution channels, and government policies [73]. The last risk factor in the market risk segment is *market novelty* (for a company or in general). This factor includes risks referring to the strongly limited predictability of future market conditions and potentials as well as the low customer and competitor experience of the company in new markets [11, 78]. While for existing markets the customer and competition analyses are much easier and more reliable, novel markets offer significantly higher growth potential compared to existing, saturated markets [55, 80].

5.2.6 Monetary Risk

In the sub-risk cluster of monetary risks, the main risks mentioned in the literature are *fundraising* [42] and the *costs* associated with development, production, and market introduction of the technology or related products [19]. Especially the investment in new technologies is associated with high default risks for investors, and thus *fundraising* also poses a major risk in the development phase of new technologies. This can lead to either poor credit conditions and therefore higher costs of debt financing [29] or to a payment gap, which can threaten the development or implementation of the technology [31]. Due to the novelty of the technology, poor predictability of the *costs* incurred is also to be expected [44].

6. Conclusion and Outlook

This paper aims to identify and structure technological and economic risk factors associated with the development and implementation of new technologies. As a basis for the determination of the risk factors, systematic literature research according to BROCKE ET AL. was carried out to guarantee the traceability as well as the credibility of the research. The research resulted in 19 distinguishable risk factors, which were clustered into six sub-risks. The identified risk factors contribute to the understanding of the risks associated with new technologies. Thus, these risks can be considered in the assessment and selection process for new technologies to increase the reliability and validity of the assessment. It should be noted that the developed systematization of the risk factors does not claim to be exhaustive, since a reduction and aggregation of information is required to limit the complexity and ensure applicability.

As already mentioned, risk identification is only the initial step in the risk assessment of technologies. The risk factors identified in this paper serve to improve the understanding of potential risk sources, which is a prerequisite for an adequate risk assessment. Furthermore, a weighting of the factors is required for the risk assessment to be able to calculate the total risk for a technology. This weighting should be carried out by the company to address the company-specific circumstances and enable the individual assessment of technologies. The evaluation of the technology risk can be done subsequently using a use-value analysis or similar scoring approaches.

Besides the identified risk factors, it is necessary to investigate other types of risk, such as legal risks or organizational risks, in the course of further research to comprehensively capture the risks associated with the development and implementation of new technologies. Also, validation of the research results based on empirical studies is necessary to verify the identified set of risk factors according to their practical relevance.

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